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USAAVLABS TECHNICAL NOTE 6

SURVEY AND EVALUATION OF ELECTRICAL POWER SOURCES AS TO THEIR POTENTIAL APPLICATION WITH THE 500-POUND CONTROLLED AIRDROP CARGO SYSTEM

By

John W. Dunlop

September 1970

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

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Project 1F164204D158, House Task 70-16
USAAVLABS Technical Note 6
September 1970

SURVEY AND EVALUATION OF ELECTRICAL POWER SOURCES AS TO THEIR POTENTIAL APPLICATION WITH THE 500-POUND CONTROLLED AIRDROP CARGO SYSTEM

Final Report

By

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U. S. ARMY AVIATION MATERIEL LABORATORIES
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ABSTRACT

The purpose of this report is to determine the most suitable power source for the 500-pound controlled airdrop cargo system (CACS), considering electrical and environmental characteristics, reliability, maintenance requirements, availability, cost, and whether it can be mounted in existing systems without major design changes.

Electrical load requirements were measured and recorded. Candidate battery configurations were identified and their electrical characteristics were compared with the requirements of the system. These included primary dry, metal-air, and reserve; secondary nickel-cadmium, zinc-silver oxide, nickel-zinc, and lead-acid; static power sources; and special-purpose batteries.

It was determined that almost any power source, if allowed enough volume, weight, or complexity, would meet the electrical load requirements, but in view of the above considerations, it is recommended that:

1. The airborne portion of the 500-pound CACS be powered by a single battery consisting of 24 D-size nickel-cadmium cells.

2. The ground station (transmitter) be powered either by a single battery consisting of 20 C-size nickel-cadmium cells or at least one BA-4520 (magnesium PRC-25 battery with Standard Line Concept (SLC) connector). The BA-4520 would be external to the transmitter and would require an adaptor cord.

FOREWORD

This report compares potential electrical power sources for the 500-pound CACS. The atmospheric conditions under which the 500-pound CACS must operate are the same for any controlled airdrop system with similar capabilities. Selection of a power source for any future designs will reflect the criteria given in this report for this one system.

This report was written under the authority of Project 1F164204D158.

Most of the information contained herein was provided by Power Sources Division, U. S. Army Electronics Command (USAECOM), through furnished reports and consultations with the author. These USAECOM personnel include: Messrs. David Linden, Nick Wilburn, Allen Legath, Frank Wrublewski, Karl Nordell, Martin Sulkes, Charles Bradely, William Dudely, and A. Almerini.

Information and guidance on the 500-pound CACS were provided by Mr. J. Everette Forehand, Chief, Flexible Wing Projects, and Mr. Thomas B. Allardice, Project Engineer, of U. S. Army Aviation Materiel Laboratories.

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DESCRIPTION OF 500-POUND CONTROLLED AIRDROP CARGO SYSTEM

The 500-pound CACS is an electronically guided, gliding cargo airdrop system that can deliver critical materials and supplies to troops in remote or hostile areas at any time of day or night under a wide range of weather and terrain conditions. Because the drop aircraft does not have to fly directly over the target area, the aircrew conducting the drop is assured greater safety because the delivery aircraft can remain out of danger zones while making the drop. The CACS is currently in the Engineering Test phase.

The system consists of a parawing glider, a control unit that receives signals from a transmitter and steers the glider, the payload, and the transmitter on which the glider homes (see Figure 1). The system is capable of automatically delivering 300 to 600 pounds of cargo to within 200 feet of a ground radio transmitter from altitudes of 500 to 25,000 feet. The airborne portion, consisting of the parawing and the control unit, weighs approximately 80 pounds (excluding payload) and can be dropped from any cargo-carrying aircraft. The payload hits the ground with approximately the same impact as a parachute-dropped load, approximately 20 fps in vertical descent. Its horizontal velocity approaches 50 fps. Figure 2 illustrates the glide range of the system as a function of drop altitude.

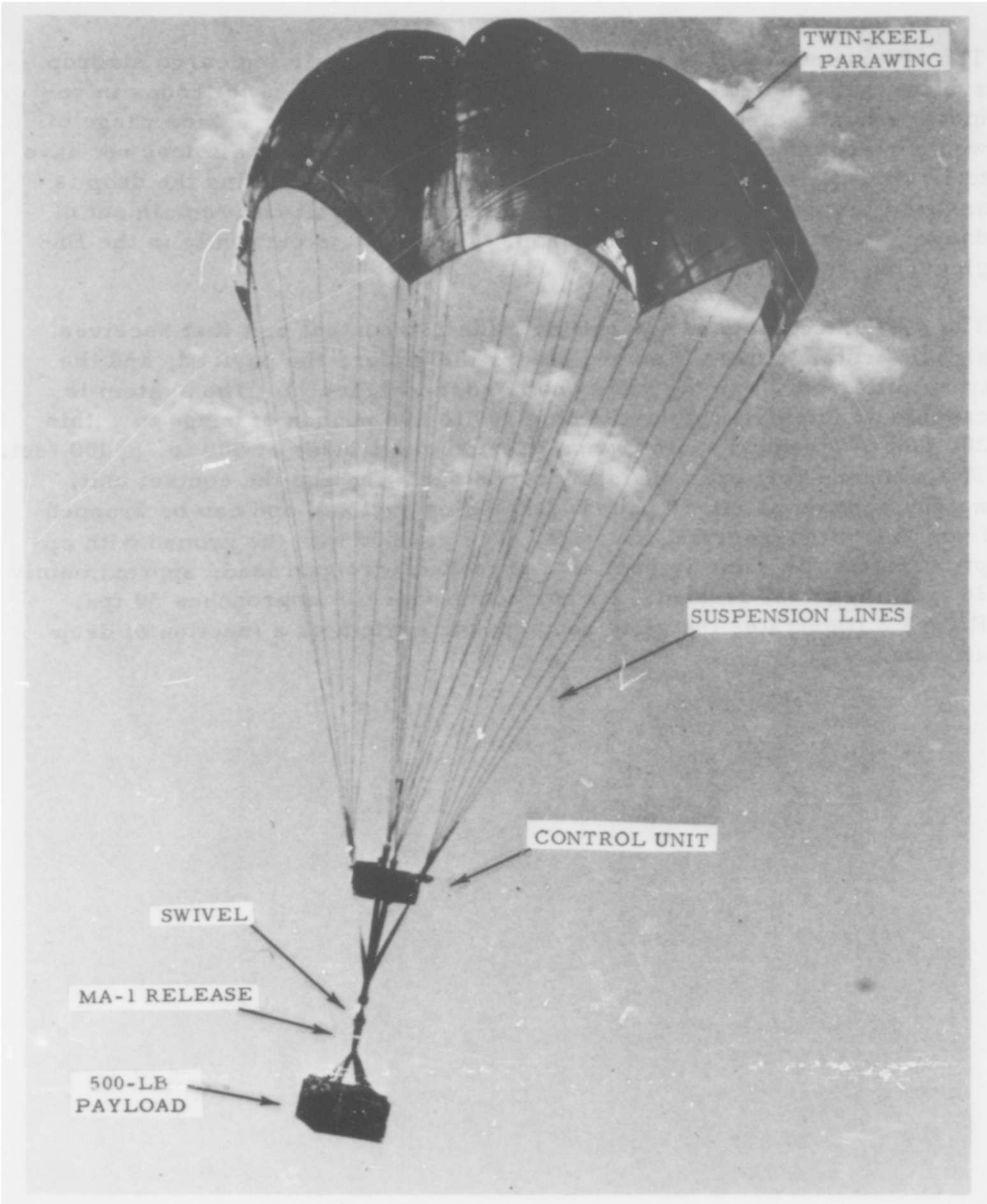

Figure 1. 500-Pound Controlled Airdrop Cargo System.

DROP CONE LIMITS	
ALTITUDE (FEET)	CONE DIAMETER (MILES) NO WIND L/D=2.4:1
500	0
1500	1.36
5000	4.55
10000	9.10
20000	18.20
30000	27.30

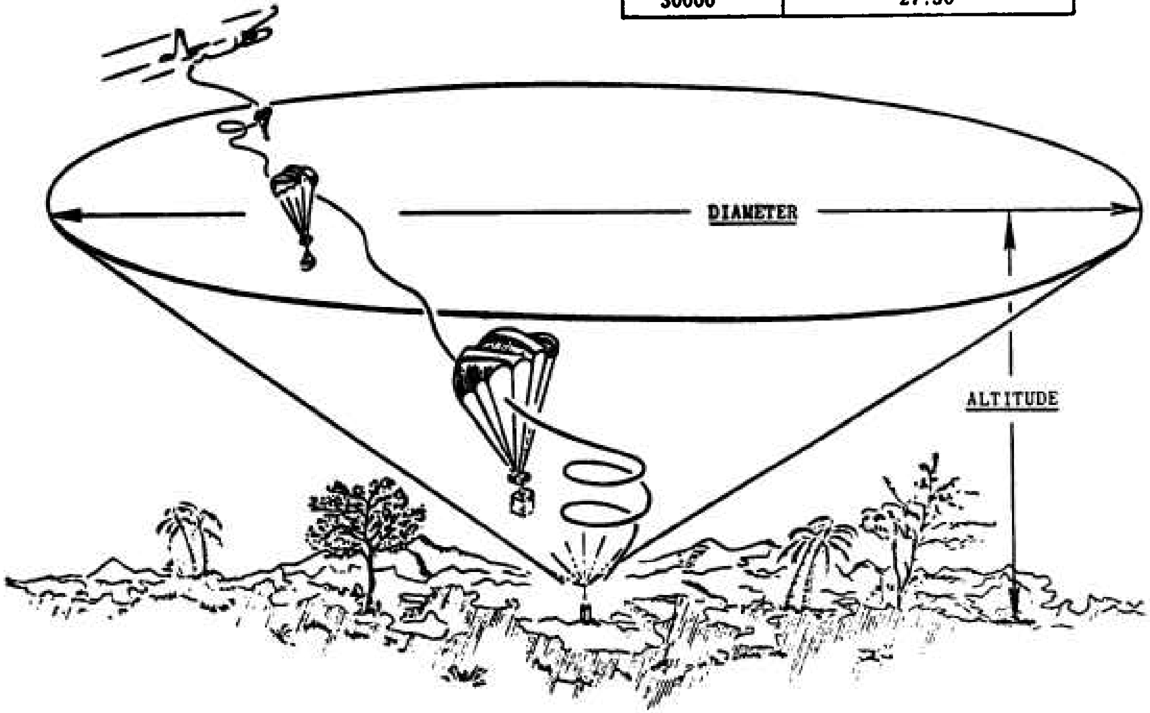

Figure 2. General Concept of 500-Pound Controlled Airdrop Cargo System.

DESCRIPTION OF SUBSYSTEMS

PARAWING

The parawing is a delta-shaped steerable glider, made of nylon fabric coated with polyurethane. It is 270 square feet in plan area, is twin-keel, and has 24 suspension lines going to 4 points of confluence on the control unit.

The parawing deploys similarly to a parachute; during flight, it assumes a three-lobe shape, the lobes coming to an apex at the leading edge. The aerodynamic lifting surface is capable of gliding 2.8 feet forward for every 1 foot that it descends. With a 500-pound payload, its forward speed approaches 50 fps.

Control is effected by pulling down on the outermost suspension lines from the line of flight. Three inches pulled in on the right or left suspension line will cause the parawing to turn 180 degrees in approximately 4 seconds.

CONTROL UNIT

The control unit is suspended between the parawing and the payload. It consists of a radio receiver with its battery, antenna array, electronic switching box, logic circuits, servomotor, servomotor amplifier, and servomotor battery pack. All are contained in a metal box 20 inches long by 21 inches wide by 7 inches high, weighing 65 pounds.

Brackets are mounted on each side of the control unit to attach the four riser straps from the parawing. The payload is suspended by riser straps from each of the four brackets. There is a swivel at the confluence of the straps where the payload is attached. The payload weight is transferred through the brackets to the parawing canopy; therefore, the control unit itself does not take the weight from the payload. The payload may be attached to the swivel by a quick-release mechanism to release the control unit and parawing upon impact. This reduces damage to the control unit.

Control is effected by two cables coming from the control unit and attaching to the outer suspension lines. The two-antenna array can sense the direction of the ground transmitter and continuously turn the parawing toward it. When directly over the transmitter, the control unit causes the parawing to execute right turns until impact with the ground.

The servomotor rotates a drum that winds the cable on each side of the unit in and out in response to the logic circuitry. The radio receiver determines if the system is to the right or to the left of the transmitter. If the system is bearing to the right of the transmitter, 2-1/2 inches of left control cable is pulled in, initiating a left turn; if the system is bearing to the left, 2-1/2 inches is pulled on the right cable. The transmitter can be switched to MANUAL, and it is then possible to control the left and right turns directly from the ground by manually depressing buttons on the transmitter.

The outer suspension lines put 30 pounds of tension load on each of the control cables. The motor is geared to operate with a maximum of 100 pounds of tension on each cable. The motor requires a nominal 28 VDC to function and draws approximately 1700 ma of continuous current during its 1 second of operation to pull in a control. The peak, or transition, load is 6 amperes each time the motor is activated. This peak load lasts less than 0.1 second.

The radio receiver in the control unit draws power from its own battery and requires a constant 210 ma.

While the servomotor is drawing current, the voltage of its battery pack should not drop below 22 VDC. If this happens, erratic operation of the servomotor occurs and it may be damaged.

The servomotor battery pack consists of 24 D-size nickel-cadmium cells connected in series. It delivers 28 ± 4 VDC, has a capacity of 4 ampere-hours, and is rechargeable.

The radio receiver battery pack consists of 20 nonstandard C-size nickel-cadmium cells connected in series. It delivers 25 VDC, has a capacity of approximately 1-1/2 ampere-hours, and is rechargeable.

The average rate of descent of the CACS is about 1000 feet per minute; therefore, the maximum time in the air from 25,000 feet is only 25 minutes. The average total power drain of both subassemblies of the control unit is approximately 2 amperes for 1/2 hour, or 1 ampere-hour. Presently, 5-1/2 ampere-hours is available from both batteries.

During engineering design of the 500-pound CACS, it was necessary to have an excess power capacity, since the electrical load requirements of the operational system were unknown. It is still desirable because of the extreme environmental conditions for which the system must be qualified. Batteries lose capacity at high and low temperatures, and a large safety margin is required. However, because of the low current drain of the radio receiver, it is possible to eliminate its battery and operate it with

the servomotor battery pack. The electrical and environmental specifications given for the control unit (page 9) are for a power source that will operate both the servomotor and the radio receiver simultaneously.

Although the present servomotor battery will furnish power for the CACS, it has some undersirable characteristics:

1. The 24 cells are not firmly mounted within the battery case, and the spot-welded connections are breaking on impact. The present rate is a connection breaking within a battery every 15 drops.

2. Present battery chargers within the Federal stock system are not suitable for charging nickel-cadmium batteries, although suitable chargers will be developed by FY 71.

3. It is difficult to determine the state of charge of nickel-cadmium cells without involved measurements or records of discharge.

4. The cell construction allows the release of the electrolyte during extensive overcharge.

5. It is difficult to charge the battery to full capacity when the ambient temperature is over 100° F.

TRANSMITTER

The radio transmitter is a portable unit with a self-contained nickel-cadmium rechargeable 25-VDC battery pack that presently is interchangeable with the radio receiver's battery pack. Provision for external power is also made. The unit may be hand-held or placed on the ground, so long as it is in an upright position. The transmitter provides an FM carrier for navigation and is used as the ground-based target for the airborne portion. It also provides for a one-way-voice AM carrier for communication with any receiver tuned to the same frequency. This capability can be used for ground-to-air communication with the drop aircraft.

The transmitter requires 660 ma of current at 25 VDC nominal voltage. There are no peak loads above 10 ma. This battery pack has the same drawbacks as the servomotor battery pack, plus the disadvantage of using a nonstandard cell size.

Operationally, the transmitter must function for at least 2 hours. This requires a battery capacity of at least 1.4 ampere-hours at the 660-ma rate.

Because of these maintenance and reliability problems, this report investigates other possible power sources, and the extent to which the problems can be overcome with the present power sources.

ELECTRICAL POWER SOURCE TERMINOLOGY

A battery is a group of cells, and a cell is one electrochemical reaction. An electrochemical reaction, in general, involves three parts: the anode, or positive, terminal; the cathode, or negative, terminal; and the electrolyte, which is the ion conductor between the two. Batteries are grouped according to chemical reaction, method of activation, and whether or not they are reusable or rechargeable. Normally, the electromotive potential, or voltage, of a cell is determined by the chemical composition rather than by its size. The voltage varies with temperature and internal resistance to current.

A battery is described electrically in terms of its voltage, which is a function of the number of cells, and its capacity. Capacity is the amount of current that could theoretically be drawn from the battery in one standard time period - usually 5, 10, or 20 hours. For example, a 6-ampere-hour battery rated at a 12-hour rate will provide 1/2 ampere of continuous power for 12 hours (12 hours x 1/2 ampere = 6 ampere-hours). This does not mean that a 6-ampere-hour battery will provide 6 amperes for 1 hour. In reality, it would put out less amperage over this period. Temperature has a great effect on capacity; the extent of the effect depends on the type of electrochemical reaction.

Batteries can be grouped into two general categories: primary and secondary. Primary batteries are not rechargeable, while secondary batteries can be used through numerous charge and discharge cycles. Primary batteries can be divided into three main categories: dry cells, wet cells, and reserve batteries. Secondary batteries are grouped into five major types: lead-acid, nickel-cadmium, silver-zinc, nickel-zinc, and silver-cadmium. Other types of batteries include thermal, metal-air, fuel, solar, nuclear, and biochemical.

Since power source technology is a very dynamic field, the above breakdown is not exact. For instance, metal-air batteries can be mechanically recharged by replacing the anode and electrolyte, and could be considered either primary or secondary batteries.

ELECTRICAL AND ENVIRONMENTAL REQUIREMENTS

Electrical load tests on the 500-pound CACS control unit were conducted by USAECOM to determine the exact load profile of the servomotor, radio receiver, and transmitter.

CONTROL UNIT

Characteristics of a control unit power source include the electrical requirements for the radio receiver and servomotor. The control unit power source must be able to:

1. Satisfy a voltage requirement of 28 ± 4 VDC.
2. Provide an average current drain of 2.0 amperes.
3. Supply a transition load of 6.0 amperes every 2 seconds for less than 0.1 second.
4. Provide voltage that does not drop below 22 VDC during transition load.
5. Operate both the servomotor and the receiver for 1 continuous hour.
6. Survive at -67°F and operate at -25°F.
7. Survive at +185°F and operate at +160°F.
8. Survive 35g and operate at 10g acceleration.

TRANSMITTER

The transmitter power source must have the following characteristics:

1. Satisfy a voltage requirement of 28 ± 4 VDC.
2. Provide an average current drain of 0.7 ampere.
3. Operate for 2 continuous hours at 0.7 ampere; operate for 10 minutes of the 2 hours at 1.0 ampere.
4. Survive at -67°F and operate at -25°F.

5. Survive at +185°F and operate at +160° F.

6. Survive 35g and operate at 10g acceleration.

OTHER CONSIDERATIONS

It is desirable that the control box and transmitter be capable of using a primary battery in the event that an area does not have electrical power or a battery charger. A primary battery would eliminate recharging and keeping track of the battery's state of readiness. These factors must be weighed against the logistical problem of supplying and stocking the battery. Also, the cost per mission might become prohibitive for resupply of a primary battery on a routine mission basis. Cost would include the initial cost of the battery, plus the price of the excess power in the battery that is there as a safety factor.

Two or more types of batteries could be used depending on the mission and situation. The arctic regions might need a system to operate at -65°F, and could use a reserve primary. For training or proficiency missions or a rear echelon, it would be cheaper to use a rechargeable secondary battery. Areas with limited facilities might require a throwaway primary battery.

The following factors must be considered in selecting a battery for the control box and transmitter:

1. The control unit battery pack is 6.75 inches long by 4.63 inches wide by 6.13 inches high.

2. The transmitter is capable of accepting an external power source, but the dimensions of any replacement battery cannot exceed 10.75 inches long by 4.0 inches wide by 1.0 inch high.

3. If a battery gives off liquid or vapor, modifications will be necessary to protect the other components of the control unit or transmitter.

Since obtaining a Military Specification for a battery is an involved process, it is desirable to use a battery already in the Federal stock system if it meets the requirements.

Regardless of the latitude in which the system operates, it will encounter temperatures of -37°F when dropped around 30,000 feet; therefore, a -40°F operating temperature is desirable.

If a secondary battery is used, the complexity of the charger and the charging method must be considered. A shelf life of 28 days or longer in a charged or ready-to-go state is desirable.

POWER SOURCES

INTRODUCTION

A power source for the CACS must have the following characteristics:

1. Satisfy the electrical and environmental load requirements of the present system.
2. Be compatible with present control box and transmitter configurations and dimensions.
3. Satisfy the reliability and maintenance requirements of the present system.

Another parameter is the future compatibility of the source with the Standard Line Concept (SLC). Even though a multitude of electrochemical reactions would meet the requirements, reactions that will become standard in the near future are given the most consideration.

The SLC incorporates standard output voltages (6, 12, or 24 VDC), standard input/output connector receptacle, and standard battery dimensions. Two cross sections are used: Type I (man pack) and Type II (man portable). The present dimensions of the control unit and transmitter are not compatible with either of these cross sections.*

USAECOM divides Military power sources into four broad categories: primary batteries, secondary batteries, battery chargers/power supplies, and silent static power sources.

PRIMARY BATTERIES

Magnesium-MnO_2 Dry Batteries

The magnesium-MnO_2 batteries came into field use in 1968, and because of their greater storage life and higher capacity, they will replace the carbon-zinc batteries.

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*Linden, David, and Pilla, Louis S., STANDARD FAMILY OF POWER SOURCES, Technical Report ECOM-3306, U. S. Army Electronics Command, Fort Monmouth, New Jersey, July 1970.

The conventional carbon-zinc batteries have severe limitations for Military use:

1. Poor long-term storage life.

2. Limited ability to provide high power.

3. Very limited low-temperature performance.

Control Unit

The voltage in the control unit power source cannot drop below 22 VDC without possible erratic operation of the servomotor. Because of this, the 28-VDC battery pack required cannot drop more than 6 volts. In order to avoid this drop, the internal impedance of the battery pack cannot exceed 1.0 ohm for the needed 20 cells (nominal cell voltage, 1.5). If it does, the battery will drop more than 6 volts during the 6-ampere transition loads.

$$V = Ri$$

$$R = \frac{V}{i}$$

$$R = \frac{\text{6-volt drop}}{\text{6-amp load}} = 1 \text{ ohm}$$

where V = voltage

R = resistance (ohms)

i = current (amperes)

The best alkaline primary dry cells have impedances on the order of 0.1 ohm; 20 of these in series would result in a total battery impedance of 2.0 ohms--twice that acceptable. Other prohibitive characteristics of primary dry cells are:

1. Poor low-temperature properties. The battery will not operate below -20°F, and will retain only about one-third of its capacity at 20°F.

2. Poor capacity-to-volume and -weight ratio.

Transmitter

The current required to operate the transmitter is 660 ma at 22 to 28 VDC without significant transition loads. It is 900 ma if the TALK

(one-way audio communication) mode is used. The transmitter internally reduces the 28 VDC input to 22 VDC; one of the standard PRC-25 primary batteries, with a nominal 24 volts and approximately 3 ampere-hours capacity, will operate it for well over 2 hours.

Six magnesium-MnO_2 dry battery configurations will be procured as part of the SLC;* two of these, BA-4520 and BA-4521, have 12/24 volt cell combinations. BA-4520 has the larger capacity and discharge rate capability.

The height of battery BA-4520 is 2.0 inches. This battery is too large to be put inside the transmitter, but it could be used as a portable external source. For cold-temperature operation, BA-4520's could be connected in parallel until enough current was put forth for the transmitter to function. This could be noted by the integral galvanometer on the transmitter face.

No transmitter modifications would be required, but a connector between the transmitter external receptacle and the battery would have to be provided. This would be a cable with an external power jack on one end and an SLC six-pin connector on the other. The six-pin connector is wired to draw 24 volts.

Other combinations of primary magnesium-MnO_2 dry cells will power the transmitter. However, the BA-4520 will be the most readily available in the field.* The zinc PRC-25, 14.4-volt batteries that are still in the field will also power the transmitter if two are connected in series. They do not have the six-pin connector such that they can be wired for at least 24 volts.

Zinc-Air Batteries

The "metal-air" mechanically rechargeable battery is a new innovation emerging from USAECOM R&D. There is space between each individual cell and the next for air to circulate. This greatly increases the efficiency of the oxidation-reduction reaction of the cells and makes it possible to get as much as 100 watt-hours per pound from a battery.

The SLC zinc-air battery is activated by the addition of $Zn/KOH/O_2$ electrolyte or water. The battery is rechargeable by replacing the zinc anodes and electrolyte of each cell. It is considered a primary battery

* Ibid.

since it is not electrically rechargeable, and will find applications where primary batteries are now being used.

In the SLC, five zinc-air batteries will be activated by the addition of $Zn/KOH/O_2$. These batteries will have capacities from 20 ah to 300 ah. There will be two water-activated ($Zn/KOH/O_2$) batteries with capacities from 10 ah to 40 ah.

Control Unit

The control unit requires a maximum of 1 ampere of current to operate during its mission. The smallest capacity of a 24-volt zinc-air battery available without development is 20 ah; 95% of the battery power would be lost and wasted, since the reaction cannot be stopped. In view of more tailored SLC primary batteries, this battery is not needed.

Transmitter

The BA-4520 battery or the zinc-air battery could be used as an external power source for the transmitter. Any of the 24-volt batteries could power the transmitter for days.

The same connection used to the BA-4520 from the transmitter could be used to the zinc-air BA-525, BA-526, BA-527, BA-528, BA-529, and BA-535 batteries.

Reserve Primary Batteries

The cells in this type of battery are activated by the addition of an electrolyte. They stand dry and usually sealed until use; and depending on the cell reaction, the electrolyte can be a multitude of chemical compounds. These batteries can deliver high rates of current and/or voltage at low cost, in situations where the battery will not be recovered. Usually the reaction is very exothermic and finds wide low-temperature applications. The most common reserve primary battery is the water activated. Like other reserve primaries, its voltage is not very stable as compared to secondary batteries. Because of the wide range of possible voltage and current combinations, activation methods, and their specialized applications, the battery is usually designed around its mission. An example of this is the radiosonde water-activated battery used by the U. S. Army Signal Corps in its weather balloons.

The reserve primary battery is activated on the ground with tap water before release. It generates a large amount of heat that is dissipated as the balloon ascends to higher altitudes and encounters lower temperatures.

The battery is designed such that its temperature increases at a rate that is a function of its ascending rate. This keeps the reaction temperature down and allows the battery to produce a relatively stable voltage. Any other application of this battery would lead to complications such as the water boiling off in a short time, or the voltage going to a peak and then tapering off to zero without flattening off at its working level.

USAECOM uses a magnesium perchlorate ($Mg-MnO_2$) reaction in its SLC reserve primary battery. This battery is designed for moderate power requirements over a temperature range of -40°F to +165°F. It complements the zinc-air battery for a low-temperature high-rate primary battery. It can be designed for either manual, remote, electrical, or mechanical activation. Two 12/24 VDC batteries will be available in the SLC: BA-838 and BA-839. The BA-838 battery weighs 4 pounds and has a capacity of 5 ah at 24 volts; the BA-839 weighs 6 pounds and has a capacity of 11 ah at 24 volts.

Control Unit

Reserve Primary Power Sources Division, USAECOM, conducted electrical load tests on the BA-838 battery with the control unit load profile at -40°F and at +80°F.

Both tests were satisfactory; the BA-838 voltage did not drop below 22 VDC during the 130 minutes at 80°F and 140 minutes at -40°F except briefly to 21.5 VDC at start plus 15 minutes (see Figures 3 and 4).

At -40°F, the battery requires 2 to 3 minutes' activation time after the magnesium perchlorate solution is added. This would be unacceptable if the battery were activated upon deployment at -40°F, since the system would descend approximately 4000 feet before it picked up its proper heading. This could be avoided by activating the battery before deployment, since it will retain at least 75% of its 5-ah capacity after 7 days.

The BA-838 in its present SLC dimensions will not fit into the present control unit. However, a representative from the battery's manufacturer foresaw no technical difficulties in fabricating the 16-cell structure of the BA-838 into the dimensions of the present servomotor battery pack. More cells could be added to increase the voltage if desired.

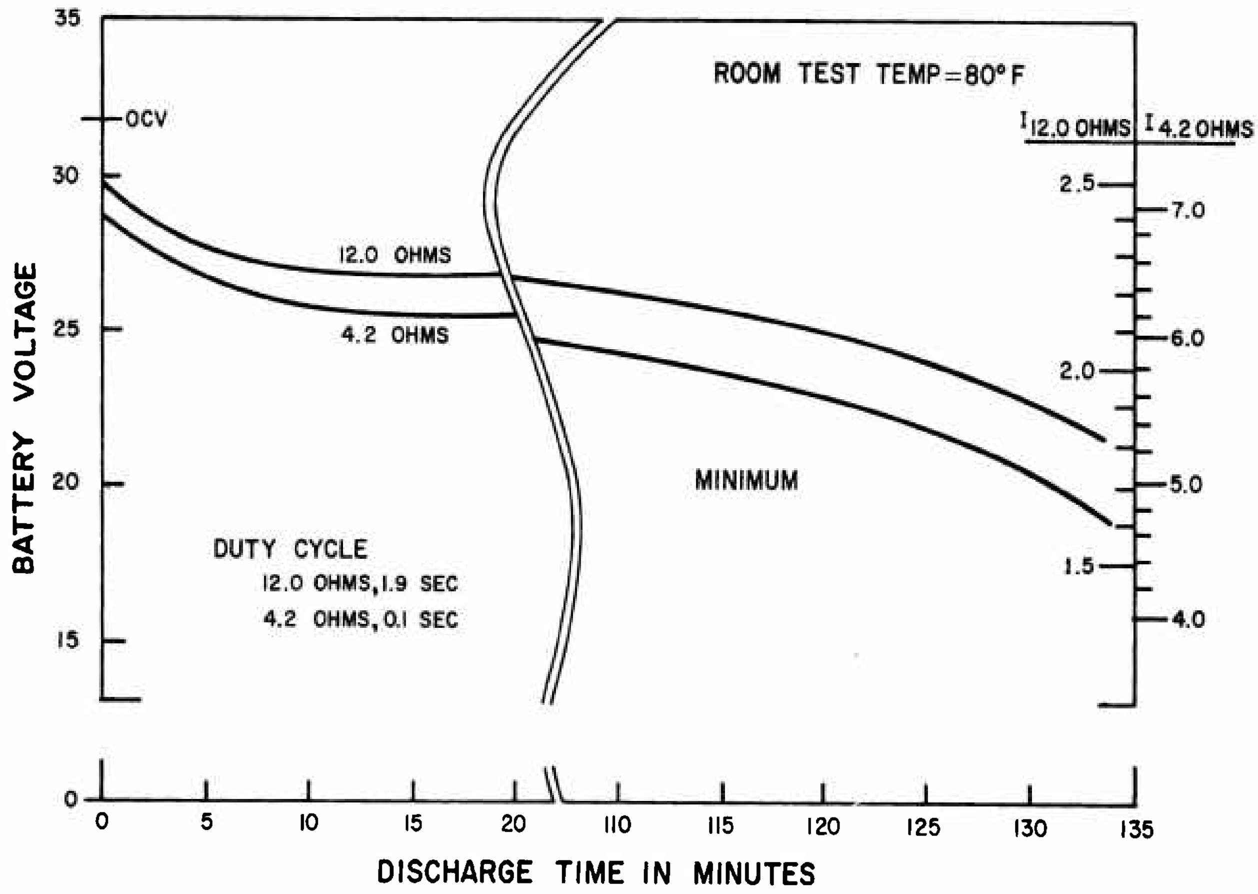

Figure 3. Flexible-Wing Application, BA-838/U (80°F).

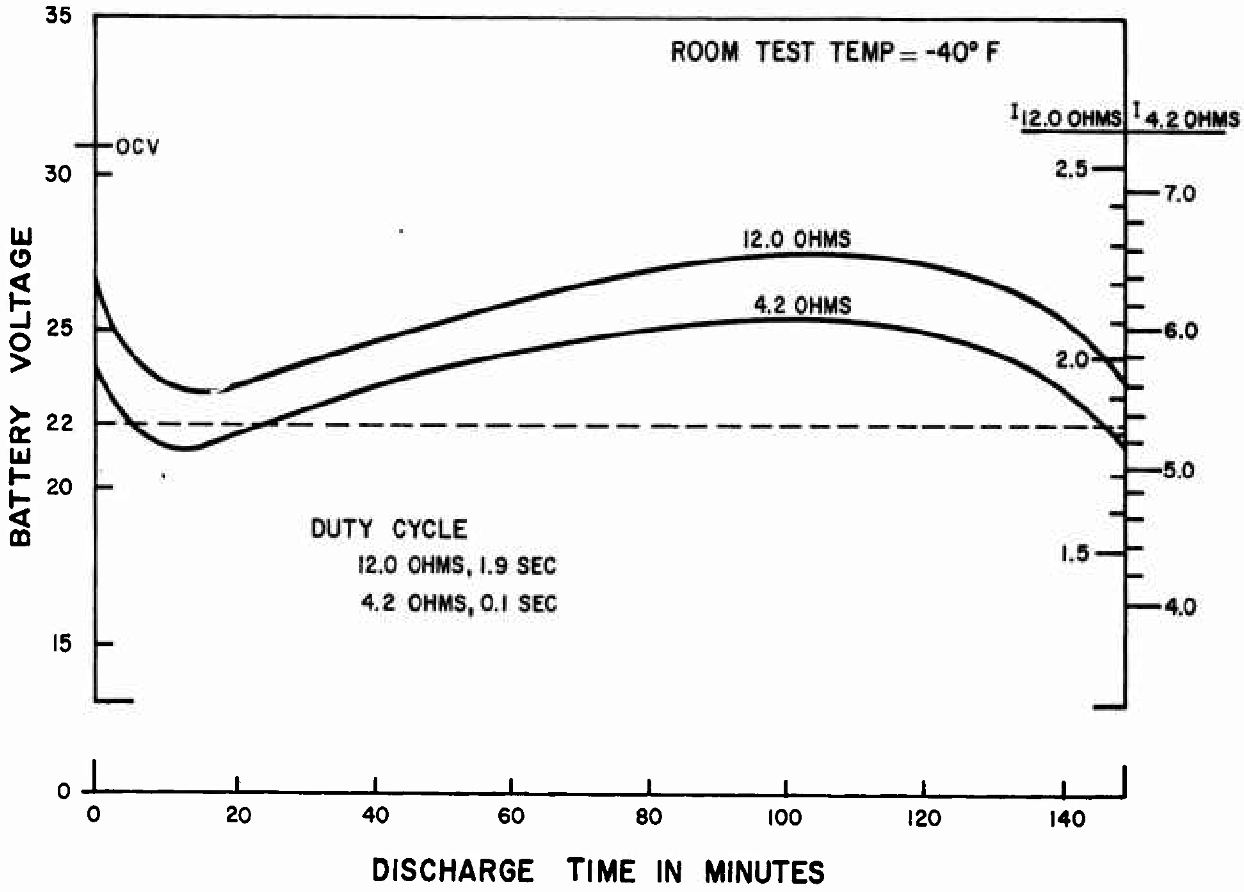

Figure 4. Flexible-Wing Application, BA-838/U (-40°F).

To use the BA-838 battery in the control unit would require:

1. Redesigning the battery or the control unit dimensions.

2. Designing an activation device, and modifying the sequence of deployment to initiate this device.

3. Shielding the battery compartment from the other components to protect them from possible corrosion from the electrolyte. (The magnesium perchlorate is about as corrosive as sea water, and is nonflammable.)

4. Revising operational and maintenance manuals to incorporate any modifications.

Transmitter

Either the BA-838 or the BA-839 battery would make an excellent low-temperature power source for the transmitter. Although both of their capacities are excessive, and their size and weight are undesirable for a man pack, they are presently the most reliable batteries in the SLC for temperatures below -25°F.

SECONDARY BATTERIES

The Standard Line Concept will incorporate four types of electrochemical reactions in its family of secondary batteries: lead-acid, nickel-zinc, zinc-silver oxide, and nickel-cadmium.

Lead-Acid Batteries

The new SLC maintenance-free lead-acid battery is a vast improvement over present lead-acid batteries. Nevertheless, the electrochemical reaction itself has a severe limitation. At -20°F, the lead-acid reaction loses approximately two-thirds of its rated capacity. Below this temperature, the reaction becomes increasingly more unreliable. Since the airborne portion will always experience temperatures at least this low when dropped at high altitudes, any lead-acid battery would be operationally marginal.

There are electronically guided parawing systems that use lead-acid batteries to power their control units. One of these batteries is the Globe "gel/cell." It is a lead-acid reaction with a gelled electrolyte. This battery was investigated for possible use with the 500-pound CACS by Secondary Power Sources Division, USAECOM. A -25°F cold test was

conducted on two "gel/cell 1245" batteries connected in series. The control unit was manually operated for approximately 10 minutes before the batteries' voltage dropped below 17 VDC and the unit began erratic behavior. The "gel/cell" is an inexpensive, easy-to-charge, reliable battery if the temperature is not extremely cold. It could be used for drops below 20,000 feet in temperate latitudes.

Although lead-acid batteries are not as reliable at low temperatures as other reactions, they could be used with the transmitter reliably since the transmitter indicates if it has enough power or not to the man operating it.

Zinc-Silver Oxide Batteries

Of the four possible secondary reactions, the zinc-silver oxide battery offers the highest watt-hours per pound. Unfortunately, USAECOM does not recommend it for use below -20°F. This battery is expensive to fabricate and is used where light weight is essential. Since weight is not a critical factor with either the transmitter or the control unit, there is no necessity for a zinc-silver oxide battery. This battery could provide an external source to the transmitter.

Nickel-Zinc Batteries

The nickel-zinc secondary battery is almost as inexpensive to fabricate as the lead-acid. However, the nickel-zinc reaction is recommended for use only above -22°F. It would be possible to design a nickel-zinc battery to power the control unit, but this would be unnecessary since other reactions have better low-temperature properties at competitive cost. As with the other secondary batteries, it could provide an external power source to the transmitter.

Nickel-Cadmium Batteries

Vented nickel-cadmium batteries are extremely rugged and are capable of good field service. For applications in new hybrid configurations and in lower power electronic equipment, batteries using sealed NiCd cylindrical cells have been developed for the SLC. NiCd batteries are operational down to -40°F, and are the only batteries of the four that give good reliability at -25°F.

The NiCd battery will continue to put out its rated voltage until almost all of its capacity is spent. It is capable of very high rates of discharge, and it will accept overcharges with little or no damage. SLC NiCd batteries are designed for a minimum of 1000 cycles, and will accept a charge even at -40°F.

The NiCd battery has some undesirable properties:

1. Its state of charge is difficult to determine without complicated measuring techniques or accurate records of discharge.

2. If discharged over and over again at the same rate for the same length of time, the battery will "remember" after a while and will give up only this amount when more is asked of it.

3. At temperatures above 100°F, increasingly large amounts of current are required to charge the NiCd cell.

Control Unit

The present control unit uses 24 NiCd D-size cells. It is rated at 28 ± 4 VDC with a capacity of 4.0 ah. This capacity is four times the 1.0 ah maximum needed for a 25,000-foot drop. At -40°F, this battery loses only 50% of its rated 70°F capacity. Since the voltage is still 28 ± 4 VDC at 50% capacity, the control unit retains twice the maximum needed power at its most extreme condition of -40°F.

Within the SLC, four vented cell batteries and five sealed cell batteries will be available. Of these nine batteries, BB-607, BB-630, and BB-655 are the most suitable. All have 24 VDC systems; they have capacities of 5.5 ah, 4.0 ah, and 7.0 ah respectively. All have the Type I (man-pack) configuration of the SLC.

Since the present 500-pound CACS control unit servomotor is designed for 28 ± 4 VDC, the 24 ± 4 VDC available from the above batteries would provide marginal electrical power. For this reason, and also because of the complexities involved in modifying the control unit to accept the Type I configuration, it is recommended that the present battery be retained as the secondary power source.

Although there is presently no battery charger in the Military system suitable for charging NiCd cells, several are being developed by USAECOM and should be fielded about the same time as the 500-pound CACS (see Battery Chargers).

Transmitter

The transmitter is designed to take a 20-cell C- or sub-C-size battery pack. Since the other SLC secondary reactions do not have the configuration to fit into the transmitter battery pack, the present pack must be retained, or provisions must be made such that 20 NiCd cells can be loaded into the transmitter. This would involve

fabricating a "rack" to hold the batteries on the transmitter cover that holds the present battery.

BATTERY CHARGERS

The lead-acid battery is the present backbone for portable power in the Military. This is changing. Nickel-cadmium batteries, with their extreme ruggedness, reduced maintenance, and wide operational temperature range, are coming to replace the lead-acid batteries, especially in aviation where high discharge rate capability and reliability are important. Zinc-silver oxide batteries are being used where weight is of paramount importance.

Chargers are under development at USAECOM that will be capable of recharging all SLC secondary batteries and any other moderate-sized NiCd, zinc-silver oxide, lead-acid, or nickel-zinc secondary batteries.

Automatic battery charging is highly desired for all secondary batteries used with forward-area equipment. Manual chargers require excessive manpower, often damage the batteries being charged, and are generally unsuitable. A versatile charger has been developed (PP-4126) in both a DC and an AC power input version. It is capable of automatically charging any of the standard batteries used by the Military.

Simplified and specific charger versions are available for specialized applications:

1. The PP-4125 charger is a simplified lightweight version that can automatically recharge Military batteries from a vehicle or vehicular electrical system.

2. The PP-4127 charger is designed to charge two 6-V zinc-silver oxide batteries simultaneously.

3. The PP-6309 and PP-6310 chargers are versions of an automatic charger for 24-V zinc-silver oxide batteries.

In conjunction with the above equipment, power supplies have been developed to power equipment in semi-fixed locations where AC power is available. These power sources have been designed to charge Military secondary batteries. The PP-6244, PP-6224, and PP-6245 chargers can all charge nickel-cadmium batteries. They cannot operate automatically, as the PP-4126 does, but must be set and shut off.

Power Supply PP-6148( )/U is designed to interface with the Type I (man-pack) cross-section radio sets and charge nickel-cadmium batteries, both vented and sealed cells. Input is a standard AC 115/230 volt, 50/60/400 Hz outlet.

SLC man-pack and stationary, thermoelectric, and fuel cell power supplies are under development at USAECOM. These devices will charge batteries using hydrocarbon fuels and will not need electrical power inputs. Those that could charge a 24-volt NiCd battery are:

PP-6303( )/U: Thermoelectric Battery Charger and Power Supply

PP-6343( )/U: Thermoelectric Battery Charger and Power Supply

PP-6335( )/U: Man-Pack Thermoelectric Battery Charger and Power Supply

PP-6149( )/U: Hydrazine-Air Fuel Cell

PP-6150( )/U: Hydrazine-Air Fuel Cell

PP-6151( )/U: Hydrazine-Air Fuel Cell

Fuel cell battery chargers PP-6203 and PP-6204 were designed to be used with SLC NiCd batteries to power transceivers. They need no AC or DC power input, only their specialized fuels.

Of the above equipment that will charge nickel-cadmium batteries, the most immediately practical is the PP-6148 power supply. The PP-4126 battery charger will be the standard, but it is a few years away from Type classification. PP-6148 weighs only 19 pounds and has been qualified by Engineering and Service Testing. Present cost is $3000 to $4000, but USAECOM estimates a production cost of about $1500. Even though it is designed to interface with the Type I cross section, it retains its SLC connector and would only need to be jumped into a nonstandard battery.

Until an SLC charger is available, commercial chargers could be procured and included with the CACS maintenance package. This is not totally undesirable since the NiCd battery is recharged (usually) by a simple constant-current method. Constant-current chargers are inexpensive ($15 to $30 and up).

Another alternative is to build a constant-current charger right into the control unit while providing one with the transmitter. A disadvantage of this would be the inability to adjust the current to increase the charging rate with temperature. Also, two separate chargers would be needed,

since the transmitter battery and control unit battery are charged at different rates.

SPECIAL-PURPOSE BATTERIES

Special-purpose batteries are designed for the unique requirements of missiles, meteorological equipment, laser devices, special weapons, and other equipment. The SLC dimensions cannot fit every situation, but where practical, the same electrochemical reactions are used. The secondary power source batteries recommended for the control unit and transmitter fall into this category. They are the accepted and common nickel-cadmium cells in nonstandard configurations.

Using an SLC reaction will reduce development problems for future systems. The same power source maintenance procedures will be followed for any design of equipment. All that will be required is to design the future battery compartments with a Type I cross section, since the actual cells will be common to both present and future batteries.

OTHER POSSIBLE POWER SOURCES

Almost any source of electromotive force could power the CACS if allowed enough size, weight, and/or complexity. These sources include: solar cells, thermobatteries, fuel cells, biochemical reactions, nuclear batteries, solid-state batteries, and fluorine-lithium reactions. There are a multitude of ways of fabricating a cell using any reaction. The nickel-cadmium cell can be constructed using sintered, pocket, or tubular positive plate in either vented or sealed cell construction. Reserve primary batteries can be activated manually, electrically, remotely, or mechanically. Their electrolyte can be tap water, sea water, distilled water, KOH, acid, or magnesium perchlorate.

Because power sources exist in the Standard Line Concept that can power the CACS, it is impractical to use a source that is not in this concept. Using a standard power source increases an equipment's combat effectiveness by increasing reliability, reducing maintenance procedures, and easing resupply of an item.

SELECTION OF POWER SOURCES

MAIN POWER SOURCES FOR CONTROL UNIT

The control unit during operations is to be recovered and returned to a rear area, allowing low cost per mission if a secondary battery is used. Although the cost per mission of a primary battery is competitive, the control unit would require extensive modifications to incorporate the type of primary that would work. A dry cell primary will not meet the requirements; a reserve primary of nonstandard dimensions would be required. Development would include designing the battery configuration and its activation mechanism, changing existing operational procedures and manuals, redesigning the control unit to incorporate a battery compartment that is sealed off from the other components, and flight-testing the entire system.

The nickel-cadmium reaction is the only one of the four possible standard secondary reactions that is reliable at low temperatures. The sealed D-size cell is desirable for the following reasons:

1. In view of the numerous uncertainties involved when using the NiCd cell, it has a large safety margin of power.

2. The present battery pack uses the D-size cell, and its reliability has been qualified. The additional drain of the receiver is very small when compared to the large safety margin of 4 times the maximum power.

3. This cell will be in keeping with the SLC.

4. Chargers are being developed that will charge the NiCd cells.

5. Changes in wiring and procedures would be minor.

6. A shielded battery compartment is not required.

7. The present program of testing would not be delayed.

The NiCd cell battery should consist of 24 hermetically sealed, D-size, welded-edge, nickel-cadmium cells using an SLC connector and potted, or similarly constructed, to withstand the numerous high impact forces.

MAIN POWER SOURCES FOR TRANSMITTER

When the transmitter is opened to insert a battery, the internal parts and frequency-selection adjustments of the radio are exposed; therefore, it is desirable that the transmitter not be opened in the field. This excludes the use of a primary battery internally. The only secondary reaction that meets the requirements is the NiCd. D-size cells are too large. Standard C-size NiCd cells are desirable for the following reasons:

1. They have electrical properties very similar to the nonstandard C-size which is used in the present battery pack and has been qualified.

2. No development is required, only performance testing.

3. They are less expensive than the nonstandard C-size and are readily available.

An external dry primary portable power source is now available in the PRC-25 battery BA-4520. This battery is part of the SLC. The transmitter carrying case could easily incorporate a pouch for the battery and the jumper cable.

ALTERNATE POWER SOURCES FOR CONTROL UNIT

Reserve Primary Source

To use SLC magnesium perchlorate low-temperature reserve battery BA-838( )/U as a power source for the control unit, the following would be required:

1. Design and fabricate the battery to fit in the control unit.

2. Design an activation mechanism, and establish procedures for its initiation.

3. Modify the control box to accept the new battery configuration, and provide a battery compartment that is sealed from the other components. This would protect them from any electrolyte that escaped from the battery.

4. Revise maintenance procedures and manuals.

Production costs for the magnesium perchlorate reserve battery would be a function of the $10 worth of cell materials in the battery. Depending on the activation mechanism, this could be quite high.

An additional disadvantage of this battery, besides needing development, is that it takes 2 to 3 minutes to activate at $-40^{\circ}F$. This could be overcome by initiating the battery when the system static line is attached to the aircraft before the drop.

Emergency Field Expedient

During emergency operation, the control unit can be powered as follows:

1. Tie into the box from 20 to 26 vented or sealed NiCd cells in series to total 28 ± 4 VDC. If the cells total less than 2 ampere-hours, connect more cells in parallel to total this amount.

2. Use sealed or gelled lead-acid, zinc-silver oxide, or nickel-zinc cells if they will not be exposed to low temperatures for any significant length of time.

3. Use any combination of batteries that provides 28 ± 4 VDC for 2 ampere-hours and has a high discharge rate capability.

ALTERNATE POWER SOURCES FOR TRANSMITTER

Reserve Primary Sources

The following reserve primary sources may be used for the transmitter:

1. At least two PRC-25 zinc batteries connected in series instead of one BA-4520.

2. The magnesium perchlorate or the zinc-air battery in cold temperatures where the dry cell batteries would fail.

Emergency Field Expedients

During emergency operation, the transmitter can be powered by any dry cell combination that provides at least 700 ma at 24 ± 4 VDC; for example, flashlight batteries, which will operate the transmitter briefly, or any combination of vehicle batteries that totals 24 ± 4 VDC.

RECOMMENDATIONS

CONTROL UNIT

1. Retain the present secondary nickel-cadmium servomotor battery pack, but modify the design to withstand landing impact.

2. Eliminate the radio receiver battery, and wire the receiver into the servomotor battery pack.

3. Modify the control unit box such that an SLC connector is the charging inlet. Mount the connector on a side of the box.

TRANSMITTER

1. Use standard C-size nickel-cadmium cells, instead of nonstandard C-size cells, as the internal secondary battery pack.

2. Provide each transmitter with one external power connection adaptor to the BA-4520 and/or one power connection adaptor to connect two zinc PRC-25 batteries in series.

3. Modify the transmitter carrying case to carry one, two, or three PRC-25 batteries.

4. Design future equipment to incorporate Type I or Type II cross sections for their power source receptacle, such that any SLC battery can be used, depending on the mission of the control unit.

BATTERY CHARGING

1. Use commercial equipment until SLC battery chargers can be procured.

2. Provide the control unit and transmitter with adaptors between the present "strip connector" and the plug to an SLC six-pin connector.

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PROCEEDINGS (EIGHTH, TENTH, SIXTEENTH through TWENTY-THIRD) ANNUAL POWER SOURCES CONFERENCE, PCS Publications Committee.

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Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Aviation Materiel Laboratories Fort Eustis, Virginia	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
SURVEY AND EVALUATION OF ELECTRICAL POWER SOURCES AS TO THEIR POTENTIAL APPLICATION WITH THE 500-POUND CONTROLLED AIRDROP CARGO SYSTEM

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report

5. AUTHOR(S) (First name, middle initial, last name)
John W. Dunlop

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1970	6	8

8a. CONTRACT OR GRANT NO. NA b. PROJECT NO. 1F164204D158 House Task 70-16 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) USAAVLABS Technical Note 6 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
Each transmittal of this document outside the Department of Defense must have prior approval of U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia 23604.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U.S. Army Aviation Materiel Laboratories Fort Eustis, Virginia

13. ABSTRACT
The purpose of this report is to determine the most suitable power source for the 500-pound controlled airdrop cargo system (CACS), considering electrical and environmental characteristics, reliability, maintenance requirements, availability, cost, and whether it can be mounted in existing systems without major design changes.
Electrical load requirements were measured and recorded. Candidate battery configurations were identified and their electrical characteristics were compared with the requirements of the system. These included primary dry, metal-air, and reserve; secondary nickel-cadmium, zinc-silver oxide, nickel-zinc, and lead-acid; static power sources; and special-purpose batteries.
It was determined that almost any power source, if allowed enough volume, weight, or complexity, would meet the electrical load requirements, but in view of the above considerations, it is recommended that:

1. The airborne portion of the 500-pound CACS be powered by a single battery consisting of 24 D-size nickel-cadmium cells.
2. The ground station (transmitter) be powered either by a single battery consisting of 20 C-size nickel-cadmium cells or at least one BA-4520 (magnesium PRC-25 battery with Standard Line Concept (SLC) connector). The BA-4520 would be external to the transmitter and would require an adaptor cord.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
500-lb Controlled Airdrop Cargo System (CACS)						
Parawing Glider						
Power Sources for CACS						
Electrical Power Sources						